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## QUANTITATIVE CHARACTERISTICS OF LITHUANIA GLACIAL RELIEF

**ABSTRACT:** ČESNULEVIČIUS A., *Quantitative characteristics of Lithuania glacial relief.* (IT ISSN 0391-9838, 1998).

When the Pleistocene inland ice retreated from the territory of Lithuania, various glacial, stadial and phasal formations were left behind, which were modified by other geomorphic processes. Distinct differences can be observed concerning glacier margin formations where corner morainic tracts and connecting morainic arcs can be distinguished. Morphological differences are characterised by the following three parameters: height of landform, length and angle of slopes. Based on these parameters genetic and morphological differences of the marginal landforms can be specified. The paper analyzes the morphometry of Lithuanian landscapes and emphasizes the quantitative characteristics of glacial features of various age.

**KEY WORDS:** Morphometry, Glacial relief, Last glaciation, Lithuania.

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Quando la calotta glaciale si è ritirata durante il Pleistocene dal territorio lituano, varie formazioni glaciali, stadiali e di fase glaciale furono abbandonate e furono poi modificate da altri processi geomorfici. Marcate differenze possono essere osservate nelle formazioni glaciali marginali poiché si possono distinguere corpi morenici arcuati e archi morenici. Le differenze morfologiche sono date da tre parametri: altezza del corpo, lunghezza, pendenza dei versanti. Su questa base possono essere specificate le differenze genetiche e morfologiche dei corpi glaciali marginali. L'articolo analizza la morfometria di questi paesaggi della Lituania e sottolinea le caratteristiche dei lineamenti glaciali di varia età.

**TERMINI CHIAVE:** Morfometria, Paesaggio glaciale, Ultima Glaciazione, Lituania.

### INTRODUCTION

Pleistocene glaciers formed the largest orographical formations of Lithuanian relief (fig. 1). The investigations revealed that the existing relationship between the genesis and relief morphometrical parameters were modified by other geomorphological processes. Intensive genetical investigations of Lithuanian relief were launched in the sixties but they represented mostly the works of regional character. In 1965 the gap was filled by A. Basalykas work (Basa-

lykas, 1965). However, still for a long time the quantitative investigations of relief were not carried out. In 1981 morphometrical investigations of Lithuanian surface were launched at the Institute of Geography during which unique data were collected of relief and its quantitative indices and between quantitative indices and recent processes. This article is devoted to the morphometrical structure of Lithuanian relief emphasizing the quantitative characteristics of glacial relief of different age.

### GENETICAL COMPLEXES OF RELIEF

At the Institute of Geography a morphogenetic-morphometrical map of Lithuanian relief was compiled in 1995 on the ground of which a quantitative evaluation of relief parameters was carried out. Lithuanian relief has 15 formations of different genesis, however, only 10 of them can be mapped on a survey scale (scale 1:200 000). The remaining five are distinguished as ones supplementing the



FIG. 1 - Orographic units of Lithuanian relief.

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dominating genetical complexes (tab. 1, fig. 2) (Česnulevičius, 1995).

Using the topographical maps (Scale 1:25 000) the morphometrical parameters of the whole Lithuanian relief were calculated: height of formations, length and inclination of slopes. This made it possible to morphometrically typify the Lithuanian relief (tab. 2) (Kairiūkštis & alii, 1983). Such typification of relief allows to distinguish not only homogeneous areas of relief (types) but also to join them into complexes. The complexes are composed of relief types which belong to the same size group, e.g. 1-2, 5-6, 7-8-9.

The largest area of Lithuania's surface is taken by the formations of ground moraine (fig. 3). The ground moraine which developed during the Middle Lithuanian Phase (M.L.Ph.) predominate, but a somewhat smaller area is taken by morainic formations which developed during the South (S.L.Ph.) and North Lithuania Phases (N.L.Ph.). The mentioned three genetical complexes of ground moraine comprise a wide area of smoothed relief in Middle Lithuania, both sides of Žemaičiai Upland and

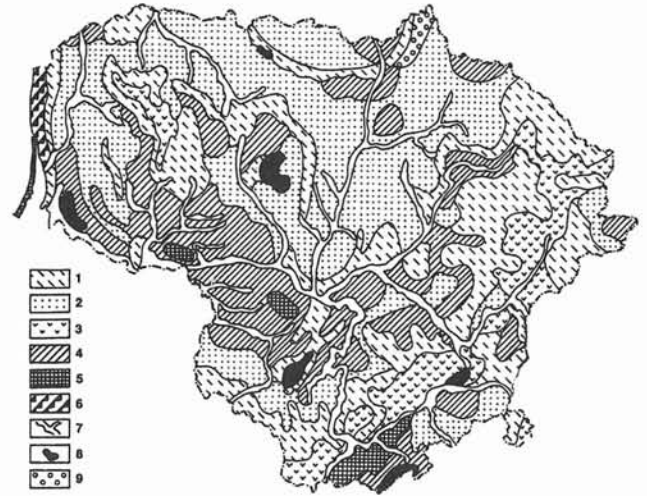


FIG. 2 - Genetical complexes of Lithuanian relief: 1) glacier edge formations; 2) ground moraine formations; 3) fluvioglacial formations; 4) limnoglacial formations; 5) eolian formations; 6) sea (marine) formations; 7) fluvial formations; 8) organogenic formations; 9) karst formations.

Table 1 - Origin and age of landforms in Lithuania

Origin	Age	Q <sub>II</sub>	Q <sub>III</sub>					Q <sub>IV</sub>	
			Brandenburg stage	Frankfurt stage	Pomeranian stage				
					E.L. phase	S.L. phase	M.L. phase		N.L. phase
Glacial edge		x	x	x	x	x	x	x	-
Glacial ground		x	x	x	x	x	x	x	-
Fluvioglacial		x	x	x	x	x	x	x	-
Limnoglacial		-	x	x	x	x	x	x	-
Eolian		-	-	-	-	-	x	x	x
Sea (marine)		-	-	-	-	-	-	-	x
Fluvial		-	-	-	-	x	x	x	x
Erosion		-	x	x	x	x	x	x	x
Organogenic		-	-	-	-	-	-	-	x
Karst		-	-	-	-	-	-	-	x
Limnic		-	-	-	-	-	-	x	x
Suffusion		-	-	-	-	-	-	-	x
Thermokarst		-	-	-	-	-	-	-	x
Solifluction		x	x	x	x	x	x	x	x
Antropogenic		-	-	-	-	-	-	-	x

TABLE 2 - Morphometrical classification of landforms

Forms and their size	Height (dept) of forms	Low (shallow) 5-10 m		Height (depth) 10-20 m		High (deep) over 20 m	
		1	2	3	4	5	6
Small (hillocks, ridges, hills, hillspurs, basins, pits, circuses, lobes, channels, gullies, ravines, valleys)	Slope length (m)	up to 50	50-100	over 100			
	Slope inclination (°)	over 7	over 7	over 7			
	Areas (ha)	1	3	10			
Medium size (ridges, hills, hillspurs, kettles, channels, ravines, valleys)	Slope length (m)	50-100	100-200	over 200			
	Slope inclination (°)	3-7	3-7	3-7			
	Areas (ha)	3	15	30			
Large (ridges, hills, hillspurs, kettles, valleys)	Slope length (m)	100-200	200-400	over 400			
	Slope inclination (°)	1-3	1-3	1-3			
	Areas (ha)	15	50	100			
Waves	10	Height (depth) of forms - up to 5 m, slope length - up to 50 m, slope inclination - up to 3°					
Plains	11	Surface inclination below 1°					

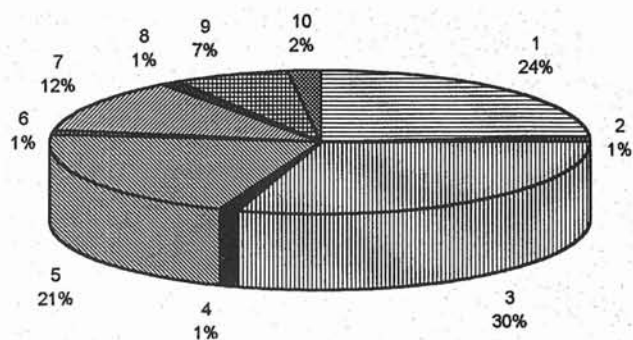


FIG. 3 - The structure of genetical complexes of Lithuanian relief: 1) glacial edge formations; 2) erosion formations; 3) ground moraine formations; 4) marine formations; 5) limnoglacial formations; 6) eolian formations; 7) fluvial formations; 8) karst formations; 9) fluvioglacial formations; 10) organogenic formations.

Northern Lithuania. Morainic formations of other periods take by far smaller areas. The formations of Middle-Pleistocene are situated in the South-east of Lithuania, whereas, phases of formation of Lithuanian ground moraine can be found on the western slopes of Baltic Upland. A small fragment of ground moraine from the mentioned period can also be observed in Middle Lithuania.

Glacier edge formations of different age take 25,2 % of the surface. They are represented by 7 belts of different hierarchy rank. Formations of Middle-Pleistocene are found in Eastern Lithuania. They exist together with the belts of formations of Brandenburg and Frankfurt Stages. A wide continuous belt (from the NE to SW extremes of Lithuania) is composed of glacier edge formations of the Pomeranian Stage of East Lithuanian Phase (E.L.Ph.). They also can be found in the central part of Žemaičiai Upland.

The glacial edge formations of the South Lithuania Phase are more dissected and take smaller areas. In Eastern and Southern Lithuania they border the western slope of Baltic Uplands, whereas, in the Žemaičiai Upland they surround the watershed part of land. The glacial edge formations of the Middle Lithuanian Phase represent a chain of wide and narrow ridge meandering in Lithuanian Lowlands. Only a few fragments of glacier edge formations of the North Lithuanian Phase have survived (fig. 4).

Fluvioglacial formations take 7,3 % of the total area of Lithuania but they are found in all age belts. The fluvioglacial deltas situated in the South-eastern Lithuania should be attributed to fluvioglacial formations of Middle-Pleistocene. The Brandenburg Stage fluvioglacial formations are represented by a few lateral old valleys descending from the Medininkai Uplands. The fluvioglacial formations of Frankfurt Stage (beginning near the western slopes Švenčionys Upland and stretching to the Lithuanian-Polish border) make a wide and almost continuous belt. A still wider belt is represented by fluvioglacial formations of East Lithuanian Phase which stretch in the same direction. They are represented by esker plains developed on the distal slope of Baltic Uplands and in many places are overbedded on the glacier edge formations of Frankfurt Stage.

The fluvioglacial formations of South Lithuanian Phase developed on the proximal slope of Baltic Uplands and filled up the north-west glaciodepression of Žemaičiai Upland. The fluvioglacial formation of Middle-Lithuanian Phase are represented by a few sectors of old valleys stretching from the Žemaičiai Upland.

21,6 % of Lithuania's area is taken by limnoglacial formations. Periglacial basins of Middle Pleistocene have not existed in Lithuania. They were situated further eastward in Byeloruss. The periglacial basins of the Brandenburg Stage have survived in the pits of Medininkai Upland and Eišiškės Plateau. More widely spread are basins of Frankfurt Stage. They are found in Eastern Lithuania. The limnoglacial formations of East Lithuanian Phase include all previous basins on the eastern slope of the Baltic Uplands and scarce glaciodepressions in the uplands. Some fragments of such basins can be found in the uplands as well as scarce glaciodepressions. Some fragments of such basins can be found in the watershed area of Žemaičiai Upland. Limnoglacial formations of South Lithuanian Phase are spread in South and Middle Lithuania and Žemaičiai Upland. Largest areas are occupied by limnoglacial formations of Middle Lithuanian Phase which are found in the central and south-western part of Lithuania. Limnoglacial formations of the North Lithuanian Phase abound. Limnoglacial formation of later period are also found. They remained from the times when the glacier stopped in Middle Lithuania. They represent a compact area at the Latvian border.

The eolian relief of Lithuania developed when the periglacial basins dried up. The largest areas taken by eolian relief developed in the Middle Lithuanian Phase. They are represented by tracts of dunes in South-eastern Lithuania taking a rather compact area. Small fragments of dunes from the mentioned period are also found in Eastern Lithuania. During the North Lithuanian Phase the limnoglacial basins dried up and dune tracts developed which

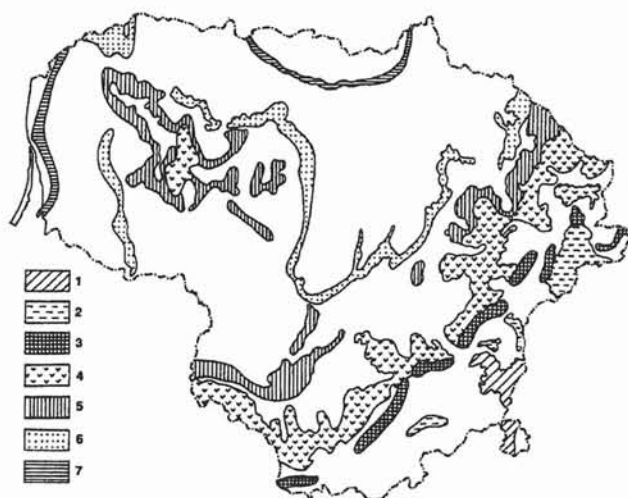


FIG. 4 - Glacial edge formations of different age: 1) Middle Pleistocene; 2) Brandenburg Stage; 3) Frankfurt Stage; 4) Pomeranian Stage East Lithuanian Phase; 5) Pomeranian Stage South Lithuanian Phase; 6) Pomeranina Stage Middle Lithuanian Phase; 7) Pomeranian Stage North Lithuanian Phase.

can be found in the south-west of Lithuania. Still another area of eolian relief is represented by the sea coast. The eolian process set in there in Holocene and still proceeds.

The marine relief is represented by a narrow belt of coast developed during Baltic Sea transgressions and regressions in Holocene. The area of marine relief is compact with abundant insertions of organogenic formations.

Large part of Lithuania is taken by fluvial formations. However, they are difficult to differentiate and therefore are studied as an uniform system of post glacial formations. The fluvial relief of Lithuania is represented by dendrite areas which are related with the valleys of concrete rivers. Such forms of secondary origin are very rare in watersheds and abound in the plain areas of Lithuania.

The fluvial relief is closely connected with the erosion relief. The latter is mostly represented by near-valley strips. We have several such type areas here in Lithuania. They are situated in the near-valley strips of large rivers. Chronologically this type of relief is not differentiated though the beginning of erosion processes can be anticipated after Brandenburg Stage in Eastern Lithuania, after Middle Lithuanian Phase in Middle Lithuania and North Lithuanian Phase in south-western Lithuania.

The type of karst relief is also rather distinctively localized. It takes a compact area. Its intensive development started at the end of glaciation after the pause of North Lithuanian Phase.

The organogenic relief is represented by bogged up former limnoglacial basins. This relief started to develop in Holocene. As the processes of bog formation continue the changes of the areas taken by organogenic relief are possible.

#### QUANTITATIVE INDICES OF GLACIER EDGE FORMATION RELIEF

While studying the morphometrical structure of relief the physiognomic differences are best revealed by com-

parison of relief of different age edge formations. Glacier tongues and lobes of different stages and phases developed two kinds of edge formations. They are represented by rather highly elevated morainic tracts and linking chains of morainic hills. Rather distinctive morphometrical differences of these different age formations were established (tab. 3, fig. 5). During the Middle-Pleistocene and early stages of Late-Pleistocene large forms of relief were developed, whereas small and middle size forms developed during the East and South Lithuanian Phases. Relief forms which developed in later phases are also large, whereas North Lithuanian Phase is represented by wavy relief. The rhythmicity was predetermined by three factors:

1. The thickness of glacier.
2. The saturation of relief with morainic material.
3. The duration of stage or phase pauses.

It becomes clear why edge formations of Middle-Pleistocene are represented by large forms. The glacier was thick and saturated with morainic material. The development of forms lasted for a long period - from several to some tens of thousand years. The glacier cover of Brandenburg Stage was also rather abundantly saturated with morainic material and rather thick. However it lasted for a considerably shorter time - some thousands of years. A still more distinctive reduction of accumulation took place in the Frankfurt Stage. The glacier was thin and accumulation lasted only for several thousand years. The glacier was also thin during all the phases of Pomeranian Stage. The East Lithuanian Phase was the longest one and besides, the material was deposited on already existing morainic elevation. This predetermined the larger and higher forms of relief. The later phases (South, Middle and North Lithuanian) lasted for a still shorter time. The ice cover was thin and the amount of morainic material contained small. This predetermined a gradual diminishing of the forms of relief.

TABLE 3 - Mean morphometrical parameters of glacial edge features of various age

Age	Location of formations	Height of slopes (m)	Length of slopes (m)	Inclination of slopes (°)	
Vistula glaciation (Q <sub>II</sub> )	morainic massives	20	320	3	
	moraine chains	16	290	3	
Nemunas location (Q <sub>III</sub> )	Brandenburg stage	morainic massives	13	160	6
		moraine chains	11	160	4
	Frankfurt stage	morainic massives	7	120	5
		moraine chains	11	200	4
	Pomeranian stage	morainic massives	13	80	8
		moraine chains	13	110	7
	South Lithuania phase	morainic massives	13	100	8
		moraine chains	10	110	6
	Middle Lithuania phase	morainic massives	6	110	3
		moraine chains	12	280	2
North Lithuania phase	morainic massives	9	150	3	
	moraine chains	6	290	1	

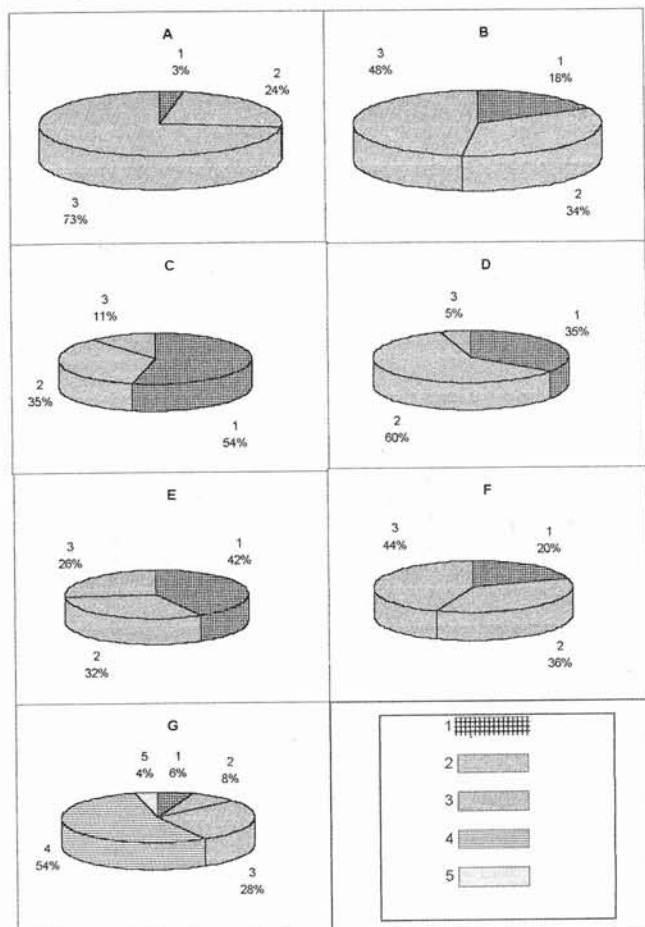


FIG. 5 - Morphometrical structure of glacier edge features: A) Middle Pleistocene; B) Brandenburg Stage; C) Frankfurt Stage; D) Pomeranian Stage East Lithuanian Phase; E) South Lithuanian Phase; F) Middle Lithuanian Phase; G) North Lithuanian Phase; 1) small; 2) medium size; 3) large; 4) waves; 5) flat planes.

## CONCLUSIONS

The complete morphometrical investigations of relief and structural analysis of morphometrical areas allowed to reveal the following regularities:

1. Accumulative forms of glacial relief include one quarter of Lithuania's territory. Different degrees of relief dis-

section can be observed in such areas, whereas smoothed surfaces take 9,7% of the total. In zones of planative action of glacier (relief of ground moraine) completely or partly smoothed surfaces predominant (82,9%). Smoothed and partly smoothed surfaces are predominant in limnoglacial (77,9%), marine (92,3%) and organogenic (100%) relief. Whereas, in the fluvial relief they make 24%, fluvio-glacial -23,1%, eolian -12,3%. In erosion relief smoothed areas are missing.

2. Relief genesis predetermined the size of morphometrical areas. Largest average areas of morphometrical types of relief observed in karst (45,7 km<sup>2</sup>), ground moraine (23,1 km<sup>2</sup>), organogenic (18,1 km<sup>2</sup>) and limnoglacial (16,0 km<sup>2</sup>) formations. Smaller areas in marine (12,7 km<sup>2</sup>), fluvial (11,2 km<sup>2</sup>), glacier edge (10,6 km<sup>2</sup>), eolian (6,8 km<sup>2</sup>), fluvio-glacial (6,6 km<sup>2</sup>) and erosion (4,9 km<sup>2</sup>) formation.

3. The smallest areas of relief were found in formations of different genesis Middle-Pleistocene and early stages of Late-Pleistocene. Starting with the East Lithuanian Phase of Pomeranian Stage the size of relief increases. This can be accounted for by an intensive oscillation movement of glacier edge in early stages and diversity of the action of geomorphological processes in the rather limited space. During the Pomeranian stage various geomorphological processes acted in a wide territory. The planational character of glacier and aquaglacial processes exerted great influence. They developed the wide plains.

4. The different number of morphometrical areas in different age relief, especially increasing in the Pomeranian Stage, is accounted for by rapid deglaciation. This preconditioned the mosaic character of genetically and concomitantly, morphometrical complexes of relief.

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